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TYPES OF COLORING IN MINERALS*

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ABSTRACT

Data relative to the various types of coloring which can occur in minerals have been collected and correlated. These types are classified and subdivided according to the means or mechanism of the color production, their characteristic features are described, and illustrative examples are cited. A fundamental distinction is made between coloring due to characteristic absorption or reflection which is determined by the chemical composition of the substance, and coloring caused by structural characteristics. Both body color and surface color are significant in the former type of coloring, while the more important types of structural coloring are those produced by interference and scattering. Other minor types are briefly described. Practical criteria are suggested for the recognition and identification of the type or types of coloring displayed in any particular specimen. An extensive bibliography is given.

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* A more extensive paper on this same general subject, containing supplementary and explanatory data, is available through *Auxiliary Publication* as *Document* No.1515, microfilm or photoprint copies of which may be obtained for 76 cents or $5.80, respectively, from the AMERICAN DOCUMENTATION INSTITUTE, 2101 Constitution Ave., Washington, D. C.

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INTRODUCTION

In the rather voluminous literature pertaining to the color of minerals there is a large amount of data and discussion regarding the presence of various chemical elements and compounds, or less commonly, physical structures, which are considered to be responsible for the particular color in question. Relatively little attention has been paid, however, to a consideration of the manner in which these elements, compounds or structures have caused the material to be colored. The purpose of this paper is to classify and describe the various types of coloring which can occur, and to propose criteria for their recognition and identification. A definite need for such classification and criteria was felt as a result of several spectrographic examinations of smoky quartz (16), blue halite (18), Siamese zircons (17), kunzite, and benitoite, which were made in an attempt to correlate color with chemical composition.

Extensive discussions of color production in nature as well as the related subjects of lustre and visibility of objects are to be found in the series of articles by Bancroft (3, 4, 5, 6, 7) and Mason (21), and in Wood (39). Many of the data presented below are derived from these sources, to which due acknowledgment must be made.

FUNDAMENTAL TYPES OF COLORING

If a mineral or other substance which does not emit any light itself is illuminated by white light, any color displayed, other than white, must obviously be a subtractive color resulting from the removal or weakening of certain components of the original white light. The mechanism or means whereby such selective weakening or removal is accomplished may be used as a primary basis for classifying the various types of coloring which can occur. There are two fundamentally different cases: (1) in consequence of the *chemical composition* of the material, part of the light is either absorbed or else suffers selective reflection which is intimately connected with intense absorption at other wave lengths; or, (2) due to the *physical structure* of the material the direction of propagation of some of the components which make up the white light is characteristically altered. In the first case we obtain *chemico-compositional coloring;* in the second case we have what is generally termed *structural coloring.* These two fundamental types may be divided further into sub-types, based on the details of the mechanism responsible.

It is to be emphasized that the color displayed by a particular specimen may be due to only one of the various causes which are to be described, or may be attributable to several of them acting at the same time. Thus the observed color might be partly chemico-compositional and partly structural, while the structural color itself might be produced in several ways simultaneously. The method of illumination and observation, the size, and the optical properties of the surrounding or contacting medium (e.g., air, water, or another mineral) may each have an effect in determining what type of coloring predominates in cases in which the observed color is due to several causes.

In the case of fluorescent or phosphorescent minerals the color observed may be modified greatly if any fluorescent or phosphorescent light is emitted. Fluorite is an example of a mineral which often fluoresces in the light commonly used for examination. Color which is due to fluorescence or phosphorescence will not be considered further in this paper, but care must be taken, in examining such minerals, to avoid confusion.

CHEMICO-COMPOSITIONAL COLORING[1]

When light falls upon a substance which exhibits coloring due to its chemical composition rather than its physical structure, part of the light is usually reflected from the surface while the rest penetrates the material. A portion of the light which actually enters may be transmitted through the substance, if the latter is sufficiently transparent or translucent; the remainder is absorbed.

The mechanism of such absorption of light energy, and hence the production of chemico-compositional coloring, may be explained on the basis of electron displacement or excitation in the absorbing material. Thus part of the energy in the incident radiation is utilized in producing excitation, from which state the energy usually degenerates into simple heat energy, or, in some cases, may be reradiated as fluorescence, or may initiate chemical reaction.

If light of only certain wave lengths is selectively absorbed, the material will display some particular hue,[2] such as red, yellow or blue; if there is strong absorption throughout all the visible portion of the spectrum, the material is said to be black.

All substances which show chemico-compositional coloring are characterized to a varying degree by both *body color* and *surface color*.

Body Color

Body color, or, as it is sometimes called, *transmission color*, is due to this selective absorption, within the colored substance, of part of the light which enters. This is a very important type of coloring in minerals, and is displayed, for example, by hematite, malachite and azurite. The amount of absorption and consequently the saturation of the observed body color may be increased by internal and other reflections which serve to lengthen the path of transmission.

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[1] The terms *pigment* and *pigmental* are often used to designate this type of coloring. However, these terms are frequently used in other or restricted senses. Their use may therefore lead to considerable ambiguity and confusion, and hence has been avoided in this discussion.

[2] Definitions and discussion of the terms used in color nomenclature and color specification may be found in the reports of the committees of the *Optical Society of America* (14, 15, 27, 35).

The color is independent of the direction of propagation of the light in isotropic material, while in anisotropic substances it may vary with the crystallographic orientation. In the latter case the color, for any given direction of propagation, depends upon the plane or planes of vibration of the polarized light. This color change which results from change in the plane of vibration of the light is called *pleochroism*, and is to be distinguished from color changes due to polychromatism. The latter are due to the fact that the hue and saturation of the color, in isotropic as well as anisotropic materials, are dependent on both the concentration of the absorbing substance and the depth or thickness of the medium traversed. These color changes have been designated sometimes by the word *dichromatism*, but the general term, *polychromatism*, which is not limited to a two-color change, is preferred by the authors. Ferric oxide is strongly polychromatic, displaying hues ranging from yellow through red to nearly black.

Surface Color

In the case of materials which absorb very strongly, light of certain wave lengths which falls upon the surface tends to be reflected selectively, thus producing *surface color*, or, as it is sometimes called, *reflection color*. The light which passes on into the material is absorbed rapidly, due to the relatively high degree of opacity. It is to be emphasized that this selective reflection of part of the light is dependent upon the chemical composition of the material rather than upon its physical structure, and is closely related to the intense absorption of the light actually entering the material. In general, there is also some non-selective reflection of part of the incident white light, thus causing a decrease in saturation of the surface color.

Selective reflection of this type can occur only when the material has a nearby absorption band, or bands. The intense absorption and the selective reflection are caused by the same mechanism, and are thus inter-related.

Typical minerals exhibiting prominent surface color are the native metals, such as copper and gold, and various oxides and sulfides which display marked metallic lustre, such as pyrite, chalcopyrite, galena and stibnite. Substances showing metallic lustre ordinarily exhibit either surface or interference color (5*a*).

The surface color of a given substance is dependent on both the angle of observation and the relative optical indices of the substance and the contacting or embedding medium (which is usually the air, but may be another mineral). Increasing the angle of incidence (i.e., moving away from normal or perpendicular incidence) tends to displace the hue toward the blue end of the spectrum. Usually this color change is not large, and, according to Mason (21*a*), is observed only at nearly grazing incidence.

Michelson (23) and Mason (21*a*) emphasize that the orientation of the plane of polarization of the reflected light is significant in determining the amount of the color change. If the reflected light is examined through a nicol prism, that light which vibrates perpendicular to the plane of incidence and reflection shows little or no appreciable change in color with increasing angle of incidence, while the light vibrating parallel to this plane shows a relatively marked color change.

The light selectively reflected at all angles other than zero is elliptically polarized to a greater or less degree; the amount depends on the angle of reflection. This property may be used as a means of distinguishing surface color from thin-film reflections, since in the latter case, according to Mason (21*b*), elliptical polarization occurs at angles greater than the polarizing angle, but is not produced at angles less than this.

The change in color produced by varying the index of the surrounding or contacting medium is described by Wood (39*a*) and Mason (21*a*) for certain synthetic dyes. Color changes of this type are probably not prominent in the case of minerals, although the observed color of a metal could easily be affected in this manner as a result of the formation of a transparent film of oxide, or other alteration product.

The selectively reflected light is often roughly complementary in color to that which is transmitted. This, however, is not necessarily the case, since the transmitted light is composed of white light minus the selectively reflected components, and also minus those removed by absorption. If the body absorption is nearly non-selective, the surface and transmitted colors are nearly complementary in hue (as in some metals), and Haidinger's law is therefore approximately obeyed; if the absorption is large and selective, the two colors may be far from complementary.

The cause of surface color has been ascribed to optical resonance (4*a*). This phenomenon also probably explains the transmission colors of thin films of metals. Thin films of gold are green, or, if thin enough, even blue (4*b*); the surface color of gold, as intensified by repeated reflection, is a red-orange (4*b*, 4*c*). Thin films of silver are blue, while the surface color, as observed after repeated reflection, is orange (4*b*, 4*c*). This change in apparent surface color on repeated reflection is simply another case of polychromatism.[3]

Effect of Size on Chemico-Compositional Coloring

The state of subdivision or absolute size of a substance possessing body color has an important effect upon the saturation of the observed color, and may affect the hue. Since colorless, transparent substances, if finely divided or powdered, appear white (e.g., snow, foam or fog, sand, chalk and powdered glass are white, while pure ice, water, rock crystal, Iceland spar and sheet glass, which, respectively, have corresponding chemical compositions, are highly transparent), due to the large amount of light diffusely reflected by their tremendously large number of surfaces, colored substances which display body color will show a progressive lightening on continued grinding or subdivision. This is attributable, of course, to the fact that the light which enters the particles is reflected out again before it can traverse more than a relatively thin layer of the absorbing material. Consequently relatively little absorption takes place, and the color due to this absorption is diluted by a large amount of white, diffusely reflected light.

The amount of diffuse reflection is increased both by increasing the fineness of subdivision (provided that the particles are not made so fine that diffraction, scattering, interference or other structural coloring becomes prominent), and by increasing the difference in index of refraction between the particles and the surrounding medium.

Conversely, the white light which is diffusely reflected can be eliminated by immersing the powder in an oil or other transparent medium which has the same index of refraction as the particles. Light which falls upon the material will then pass through greater thicknesses, and will show the original body absorption color.

Chalcanthite or common copper sulfate, for example, is deep blue in color if large crystals are examined, but, on continued grinding, the powder becomes pale blue and finally nearly white. Immersing the white powder in an oil of the same, or nearly the same, index of refraction restores the original blue color. An oil or other medium of index intermediate between the indices for air and the particles will, of course, merely reduce the diffuse reflection, and so decrease the whiteness of the reflected light. A piece of white paper or cloth, for instance, looks less white and more nearly transparent when wetted, because the air spaces between the fibers have been replaced by water which has an index closer to that of the fibers. Wet mud is likewise more deeply colored than dry mud.

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[3] The orange hue produced by repeated reflections from a silver surface may be observed very readily by folding a piece of polished silver foil into a deep, narrow V. If the open part of the V is then pointed toward the light, the orange hue may be seen on the interior surface (20).

Inclusions of a transparent, colored mineral would therefore show varying saturation, and often change in hue, depending on both the particle size and the relative indices of the inclusions and the embedding mineral.

It is well known that metals such as platinum (4*e*), silver (4*e*), gold (4*f*), copper and iron appear black when very finely divided. As the particle size increases, the characteristic surface color may also begin to appear, and will ultimately predominate. Finely divided gold, for instance, may appear black, dark brown, or yellow-brown, according to the particle size (4*b*, 4*f*). Wood (39*b*) accounts for the black color by considering that the particles form a light trap, so that the light falling upon them is absorbed by the resulting multiple reflections from particle to particle. However, this explanation does not seem entirely satisfactory.

It is interesting to note that with increasing subdivision the color of one class of substances, such as the metals mentioned above, tends to become ***black***, while in another type of materials, such as glass or blue copper sulfate, the color approaches *white*.[4] In the first case, the substances cited are relatively highly opaque, and may display prominent *surface color;* in the second case, the materials are relatively transparent, and any color shown is due primarily to ***body absorption***.

Since the color of the streak of a mineral is that of its fine powder, it may be readily seen why the color of the streak may vary considerably from the color observed in a large crystal or massive specimen. Likewise, if the mineral is composed of aggregates of minute crystals, or a compacted powder, or other fine particles, the color may vary from that shown by a single large crystal. For example, with decreasing particle size hematite may change in color from nearly black to red (which is the color of the streak), and finally to yellow (which is also the color of solutions of ferric iron) (6*a*). These color changes are prominent because ferric oxide is markedly polychromatic.

Correlation with Composition

Chemico-compositional coloring is always to be correlated with chemical composition, as shown by analysis or synthesis. The state of oxidation, combination, coordination, or hydration of the various components is highly significant. Ferrous iron, for example, is sometimes considered to cause a greenish color in minerals, although many ferrous compounds tend to be colorless. According to Bancroft (6*a*), ferrous iron alone causes little or no color; ferric oxide, however, may cause a yellow or red color, while the simultaneous presence of both ferric and ferrous iron may produce a blue. Greens are considered to result from mixtures of the blue and yellow, while red and blue together cause the appearance of purple. The ratio of ferrous to ferric iron consequently has an important bearing on the color exhibited.

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[4] This white may, under certain conditions, appear somewhat bluish (22).

Likewise, dilute solutions of manganous manganese are nearly colorless, while the same concentration of trivalent manganese shows an intense purple color. Hexavalent manganese (as in manganates) is green; heptavalent manganese (as in permanganates) is again purple. Although the two purple forms of manganese (trivalent and heptavalent) may usually appear to the eye to have the same, or a very similar hue, the absorption spectra of the two forms are very different in character (19).

If the coloring is due to absorption, chemical analysis or synthesis must consequently show the presence of a chemical substance which can act in this manner. However, the mere presence of a substance which, under the proper conditions, can cause selective absorption does not necessarily mean that the color observed must be chemico-compositional in character and due to that substance. The state of oxidation or mode of combination or coordination may be such that the resulting color is not the same as that usually associated with the simple ion or molecule indicated by the analysis.

STRUCTURAL COLORING

Structural colors are those produced when certain components in the original incident white light are selectively changed in direction of propagation as a result of the physical structure or composition of the material. The coloring therefore is not a function of the chemical composition, as such, but is dependent on physical or structural characteristics such as laminae, thin films, and minute particles, which are often of colloidal dimensions. Certain types of structures, such as those which produce prismatic or refraction colors, may be much larger. All of these structures are relatively large, however, in comparison with the molecules, ions or other units which compose them.[5]

This selective redirection of certain components means that the composition of the light which is diffracted, scattered, refracted, or otherwise selectively affected by the physical structure of the material, varies according to the direction of observation, the direction of illumination being kept constant. Consequently, for any given direction of observation, only certain components of the original white light may be seen. Another direction of observation may cause an entirely different set of components to be visible, and so cause an entirely different distribution of energy to appear. It is to be emphasized that there is no conversion of energy into another form, such as heat.

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[5] It is true, of course, that selective absorption or reflection of light is dependent upon the electronic structure of the molecules, ions, or complexes themselves, and hence chemico-compositional coloring is, in this sense, a structural phenomenon. However, the term *structural coloring*, as used in this article, has been generally adopted to designate only the colors produced by relatively large-scale structural arrangements, in which there is no conversion of energy into other forms, but only a selective change in direction of propagation.

The various types of structural coloring may be sub-classified according to the types of physical structure which produce them. Structural colors may be displayed by either transparent or opaque materials, which, in turn, may or may not show chemico-compositional coloring in addition.

1. *Interference Colors*

These are produced by the phenomenon of interference, which occurs when light impinges upon laminae, or thin films, which are usually roughly comparable in thickness with the wave length of the incident white light.

The mechanism of production consists of partial reflection of light from both upper and lower surfaces of the film, with consequent reinforcing interference for those components of the white light which have the proper wave length in relation to the effective thickness and relative index of refraction of the film. The other components of the light suffer destructive interference in reflection and are completely transmitted. Multiple reflections serve to intensify and purify the color. The colors are subtractive, since one or more of the components forming the original white light are selectively weakened or removed. The hue changes greatly and sharply, according to Newton's series, on varying the angle of incidence or observation, since the path differences in the film are changed. Increasing the angle of incidence shifts the color toward the low-order side of the series, which is equivalent to thinning the film (8). This iridescence, or change of color with angle, is a very striking characteristic of interference colors.

There are quite definite limits to the thickness of film which is effective in producing these interference colors. If the film is too thick, the colors will be greatly diluted and very weak; if the film is too thin, interference colors can no longer be obtained. Instead, selective laminary diffraction and reflection may result.

The saturation of the observed color may be affected by the geometrical character of the illuminating light. A narrow beam in which the light rays are all parallel produces greater saturation in the interference colors than does diffuse illumination.

The colors observed in precious opal are generally attributed to interference produced in thin, curved lamellae which vary somewhat in index of refraction (9). Due to multiple reflection the colors may be very pure and intense (39*c*).

In mother-of-pearl, or nacre, the more brilliant of the colors exhibited are likewise due to interference in the thin laminae which compose the inner portion of the shell. Diffraction colors also are to be observed here, but they are usually much fainter (25, 4*g*).

Parsons (24) apparently attributes the color observed in peristerite to interference due to reflection from twinning planes. He also presents and discusses extracts from the literature, many of which agree with more recent statements (10, 30, 32, 38) ascribing the iridescent coloring of labradorite to interference. Andersen (2) considers that hematite lamellae cause interference colors in aventurine feldspar.

Other examples are the brilliant interference colors displayed by oil films, as on a wet street, and by soap bubbles, and the temper or tarnish colors on metals, such as copper and steel, which are caused by the presence of thin films of oxide (21*c*). Corresponding thin films of oxides or other alteration products may account for the iridescence of minerals such as covellite and bornite.

Gaudin (12) has described a method of identifying minerals by means of the interference films which they form in a selective manner when etched or stained by suitable chemical reagents. The optical properties of such films are discussed in detail.

Interference colors are more brilliant if they are observed against a dark background, since then there is less admixed reflected white light to dilute the color. The laminae themselves need not be highly transparent in order to produce vivid coloring (although they must of course be at least partially transparent); a moderate amount of cloudiness or turbidity may enhance the vividness of the coloring by reducing the amount of admixed white light (21*c*).

The reflection spectra of substances exhibiting interference coloring show bands which may be extremely narrow and well-defined. This is particularly noticeable in cases in which the color is intensified by repeated reflections from regularly spaced laminae. The unusual sharpness and narrowness of the absorption bands in some opals (39*c*) is attributed to this cause. In general, the spectra which result from interference resemble that of the incident white light (i.e., continuous) except that one or more regions are rather sharply weakened in intensity. These regions of increased absorption may be very narrow (corresponding to the removal of only a few adjacent wave lengths), or they may be fairly broad, depending on the index, effective thickness, number and regularity of the laminae.

Interference colors can be distinguished from surface color by observing the effect of changing the polarization of the incident light; details are given by Mason (21*e*).

Interference colors may be distinguished from diffraction colors by means of a reflection test described by Stokes (33, 4*h*). This is based upon the fact that in the former the reflection is specular, although it may be from a many-planed surface; in diffraction colors there is no specular reflection.

The retardation or polarization colors which are observed when minerals are examined through a microscope with crossed nicol prisms are not to be confused with the interference colors described above. The latter are produced by the effect of the mineral on non-polarized incident light.

2. *Diffraction Colors*

These are caused by regularly repeated and properly oriented structural forms, or optical non-homogeneities, which are larger than the wave length of the light, and consequently act as a diffraction grating. The incident white light is thereby spread out into a spectrum, so that the color observed is dependent on the angles of incidence and observation, as well as on the fineness of the structure.

The sequence of colors observable with changing angle of incidence or observation follows the spectrum order. This, of course, is entirely different from the Newton sequence observed with interference or retardation colors. Also, the colors themselves are those found in the normal spectrum. Purple, for instance, is not produced by a simple diffraction grating. However, it is conceivable that there might be two sets of structures which would diffract red and blue, respectively, at a given angle. The observed color would then be purple.

Ordinary diffraction colors do not appear to be common in nature. According to Pfund (25, 4*g*), some of the fainter coloring seen in mother-of-pearl is due to diffraction arising from the regularly repeated laminae. The thin films in agate are reported to act like a diffraction grating, if the agate is properly cut (3*a*). Certain finely-striated beetle wings are said to exhibit iridescence due to diffraction (21*f*).

3. *Selective Scattering*

A. Tyndall Scattering

The term *Tyndall scattering* may be applied to the selective scattering of light by particles or structures the size of which, compared with the wave length, is small. Such scattering could be caused by colloidal particles, free electrons, meta-stable electrons, or, in general, any small-scale, optical non-homogeneity. The significant factor in all these cases is the repeated, abrupt change in refractive index between particle or structure and the contacting or embedding medium.

These particles or structures must have a relatively random orientation or positional arrangement; otherwise with a regular and suitable orientation, diffraction gratings might be formed.

In the production of this type of coloring, light is scattered in all directions by the particles or structures. The amount of the scattering, for any given direction, is inversely proportional to the fourth power of the wave length. Hence, for a certain particle size, blue may be scattered strongly and red very little. A transparent substance containing such particles would look red by transmitted light, since the red light would come through relatively unchanged in intensity. The blue light would be greatly scattered in all directions, and so the appearance of the material, when viewed in any direction except that of the transmitted beam, would be blue.

The transmitted and scattered light show hues which lie toward the opposite ends of the visible spectrum. This can usually be seen best by illuminating the material with a concentrated or narrow, intense beam of light; with diffuse illumination, the color of the scattered light usually predominates. The scattered blue is ordinarily much purer and more intense than the transmitted brown or red. This is easily explained by the fact that since the scattering is inversely proportional to the fourth power of the wave length, with particles of the proper size the scattered light is nearly all blue, while the transmitted beam is white minus blue, and blue-green, which would be brownish or reddish in color.

The intensity is dependent on the number of scattering particles, the difference in refractive index, and the angle of observation. A more intense blue can be obtained, for example, from media containing large numbers of such particles than from material containing fewer particles.

Tyndall scattering may be easily observed in the familiar Tyndall beam or cone, which appears when a pencil or cone of light is passed through a medium containing small, suspended particles. A searchlight or automobile light beam at night shows this type of scattering in the air, due largely to the dust and moisture particles contained in it. The blue of the sky is attributed to scattering by the air molecules (28, 29, 39*e*). The coloring in smoky quartz is considered to be due to scattering (13, 34, 36).

This scattered light is strongly polarized, the vibrations being in the plane normal to the direction of propagation of the incident beam. Almost no scattered light is observed through a nicol set to transmit vibrations in the plane parallel to the beam.

B. Large-Particle Scattering

The blue color weakens with increasing particle size and gradually disappears, so that the scattered light finally becomes white. Under these conditions, however, if a nicol prism is held in such a position as would ordinarily extinguish the scattered light, a blue color is again seen. This was named the *residual blue* by Tyndall, and may be much purer and more intense than the Tyndall blue produced by smaller particles. Rayleigh attributed this residual blue to a type of scattering which varied inversely as the 8th power of the wave length (29, 4*j*).

With still greater particle size, colors appear which are visible without the use of a nicol prism. In this case, on increasing the particle size, the colors change through a regular sequence which, according to Bancroft, shows an astonishing parallelism with interference colors. No adequate physical explanation seems to be available. The subject has been discussed by Bancroft and Gurchot (7).

Thus, with sulphur particles of the proper size, the scattered light is blue, and the transmitted light deep orange; with larger particles, the reverse is true, the scattered light being orange-red, and the transmitted light a deep blue (7*a*). This type of scattering is probably exhibited by blue halite, which is blue by transmitted light, and red-orange by scattered light.

In some cases the chemico-compositional color of the particles themselves adds appreciably to the observed color. This is particularly true for relatively coarse colloidal dispersions of highly-absorbing materials. Colloidal ferric oxide, for example, would be expected to show an appreciable chemico-compositional coloring in addition to the color due to scattering, provided that some of the particles were sufficiently coarse. For finer dispersions, the color observed would be essentially a function of the size and index of the particles themselves, regardless of their inherent selective absorption. For still finer particles which are colored, the phenomenon of mass resonance may appear (39*f*).

4. *Refraction Colors*

Structural colors may be caused by refraction from prismatic or globular structures which are, in general, very large in comparison with the wave length of the incident light so that diffraction and interference effects are small. The rainbow is an example of globular refractions; the Christiansen effect is due to selective non-refraction; the colored borders sometimes seen in mineral grains under the microscope when determining the index of refraction by the Becke line method are due to selective refraction. This latter color production has been described by Ambronn (1) and Schroeder van der Kolk (31).

5. *Miscellaneous Other Causes*

Possible, but probably minor causes, which are listed here primarily for the sake of completeness, are electromagnetic mass resonance (39*f*) (which is really due to a combination of structural and chemico-compositional coloring), transmitted structural blue (21*i*), mixed plates (4*i*, 39*d*), mosaic powder films (26), and various types of differential reflection from powders (22), thin films, or surfaces which may be optically smooth for long waves, such as the red, while rough for shorter ones, such as the blue.

IDENTIFICATION OF TYPE OF COLORING

The following criteria are suggested as guides for recognizing and identifying the type or types of coloring displayed. It is to be borne in mind that the observed color may be due to two or more causes, all of which can be effective at the same time. One might have scattering, for example, due to colorless particles suspended in a transparent solid, which, in itself, showed chemico-compositional coloring.

These proposed tests are therefore intended to indicate the most probable type or types of coloring observed in a particular specimen, but are not considered to result in positive proof by themselves. Other confirmatory evidence, as already detailed under the descriptions of the various types of coloring, should be sought.

1. Change in hue as a result of varying the angle of observation, or angle of incident light.

(a) *No color change is observed.* The color is therefore chemico-compositional, with body coloring predominating. (The incident light should be unpolarized if the specimen is anisotropic, in order to avoid possible effects due to pleochroism.)

(b) *A color change is observed.* If the changes in hue are prominent, and follow the sequence of colors which is to be observed in Newton's series, or in the normal spectrum, the color is structural, and is due, in the first case, to interference, or, in the second case, to either diffraction or a prismatic effect.

A very slight change in hue (especially if seen only at nearly grazing incidence), observed in minerals which have a metallic lustre, may indicate prominent surface color.

If no color change is noticed on varying the angle moderately, but if hues corresponding to nearly opposite ends of the spectrum are observed in the linearly transmitted beam and at right angles to this direction, scattering is indicated.

2. Lustre. Metallic lustre indicates either surface or interference color (5*a*).

3. Presence of certain indicative colors. Purple, for instance, is a non-spectrum color, and so is not seen in a normal spectrum, which might be formed by diffraction or a prismatic structure. It is readily caused by interference, or by chemico-compositional absorption.

White is always structural (21*g*, 21*h*), and is due to repeated, diffuse reflection. Black is always ultimately chemico-compositional. If the material absorbs strongly, very few reflections may suffice in order to produce nearly complete absorption; if the material reflects strongly, but absorbs only weakly, repeated reflections may be necessary.

4. Effects of wetting, or changing the index of refraction of the contacting medium.

Wetting or oiling often serves merely to intensify the effect of the inherent color by reducing the scattering or diffusing effect of surface irregularities. Under other conditions the color may be weakened, or even changed in hue, particularly if examined with light polarized so that it vibrates parallel to the plane of incidence and observation (37). Interference colors produced by a surface film may be weakened, or even destroyed (21*d*).

5. Polarization of the non-incident light.

Plane polarization, in cases in which it is not attributable to anisotropic properties in the material, or to favorable reflections, such as those occurring at or near the polarizing angle, usually indicates scattering. The plane of polarization should be checked for orientation.

Although this test is much more difficult to apply in anisotropic material than in isotropic substances, it is often possible to examine for polarization in the former by observing in a direction parallel to an optic axis.

6. Absorption spectra.

Due to the complexity of absorption spectra, and the relatively great difficulty in making significant measurements of the absorption curves, this criterion is perhaps of more value in confirming the deductions drawn from the other proposed tests than in making the original deduction as to the type of coloring displayed.

If several prominent absorption bands are observed, the color may often be due either to chemico-compositional absorption, or to interference. In the first case the shape of the curve is usually quite irregular; in the second case, the shape more nearly resembles that of the incident light, but with one or more prominent absorption regions.

If a band of the original light is apparently transmitted nearly unchanged, while the rest of the spectrum on either or both sides is nearly or completely removed, a diffraction or scattering effect is usually indicated. An absorbing substance could be responsible, however, as well as the Christiansen phenomenon.

7. Temperature effect.

According to Dewar (11, *3b*), colors due to chemico-compositional absorption may undergo marked changes in both hue and saturation on cooling to low temperatures, such as that of liquid air. Bancroft (*3b*) states that structural colors show little or no change under such conditions. However, coloring caused by the Christiansen effect may be very sensitive even to slight temperature changes.

ACKNOWLEDGMENT

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THE SPINEL GROUP

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Twenty years ago E. S. Simpson[1] presented in graphic form the relations between $MgAl_2O_4$ and $FeCr_2O_4$. He considered that continuous variations are possible in all parts of the system. Since that time many more analyses have been made and it seems possible to present the facts in a diagram essentially like that of Simpson, but on a somewhat different basis. It is also possible now to add lines expressing approximately the

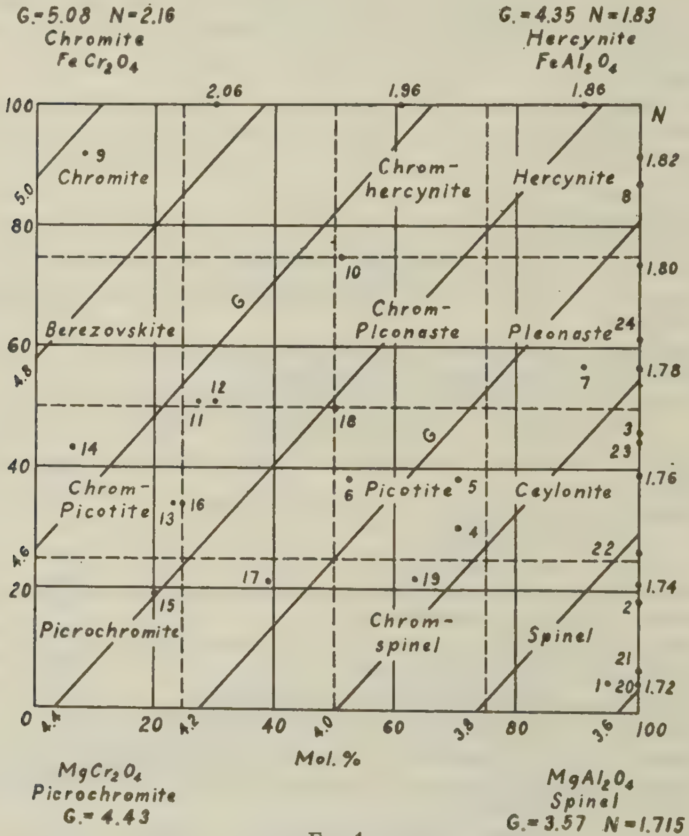

Fig. 1

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[1] A graphic method for the comparison of minerals with four variable components forming two isomorphous pairs: *Min. Mag.* **19**, 99 (1920).

variations in specific gravity which result from variations in composition. The continuity of the system seems to be beyond reasonable doubt in spite of the fact that certain areas still lack known examples.

Simpson gave names to certain portions of the system. His names are used in Fig. 1, except that he assigned the name picotite to the area between ceylonite and hercynite and alloted no names[2] to the squares adjoining these and spinel and hercynite. Since picotite is used by Lacroix for a member of this system characterized by $MgAl_2O_4$, $FeAl_2O_4$ and $FeCr_2O_4$, it seems better to assign it to some such position as shown in Fig. 1. Then perhaps the name pleonaste may be used for the area which Simpson assigned to picotite, although as a gem stone pleonaste doubtless contains less FeO than required by this area.

The diagram gives information as to the composition indicated by any point in a very simple way. Any outside line represents a binary series and, being divided into one hundred parts, the divisions represent (molecular) percentages of the two end-members. Thus, 22 represents 26% $FeAl_2O_4$ and 74% $MgAl_2O_4$. Inside the square, any point represents percentages of Fe and Mg in the vertical direction and percentages of Cr and Al in the horizontal direction. For example, 5 represents 38% Fe and 62% Mg, and also represents 70% Al and 30% Cr. Therefore 5 represents 38% $Fe(Al,Cr)_2O_4$, and 62% $Mg(Al,Cr)_2O_4$. Of this 38% $Fe(Al,Cr)_2O_4$, 70% (or 26.6% of the whole) is $FeAl_2O_4$ and 30% (or 11.4%) is $MgAl_2O_4$. And of the 62% $Mg(Al,Cr)_2O_4$, 70% (or 43.4%) is $MgAl_2O_4$ and 30% (or 18.6%) is $MgCr_2O_4$.

Of course the diagram assumes the absence of any other constituents than those which are shown. This assumption is frequently untrue, but in many cases is a very close approximation. Probably the commonest additional constituent is $FeFe_2O_4$, but spinel can apparently take only about 15 per cent of this into its structure. Accordingly, magnetite and spinel can probably form simultaneously from a magma, whereas chromite and spinel cannot.

By a study of spinel gem stones from Ceylon, Anderson and Payne[3] proved that $ZnAl_2O_4$ is miscible with $MgAl_2O_4$, at least to 35 per cent. Analyses of gahnite show that $FeAl_2O_4$ is miscible with it at least to 30 per cent, and it seems probable that $ZnAl_2O_4$ is miscible in all proportions with both $MgAl_2O_4$ and $FeAl_2O_4$.[4] Such a system is shown in Fig. 2 with lines to indicate the refractive index for all proportions. The binary series, $MgAl_2O_4$ to $ZnAl_2O_4$ is shown in Fig. 3.

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[2] Except "magnochromite," which seems undesirable to the writer.

[3] *Min. Mag.*, **24**, 547 (1937).

[4] Brauns, R.: *Cent. Mineral.*, **1927 A**, 265.

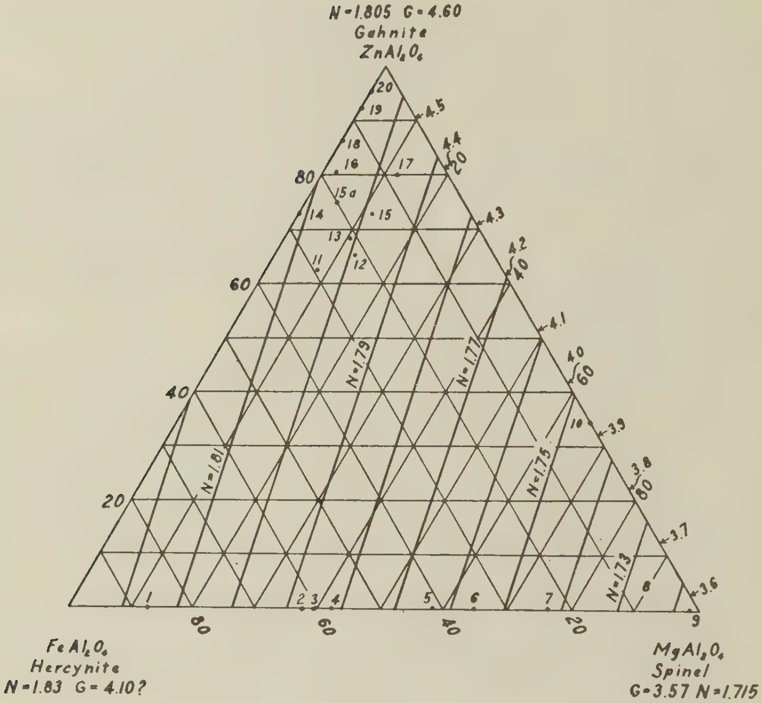
N=1.805 G=4.60
Gahnite
ZnAl₂O₄
20
19
18
16
17
15a
15
14
13
11
12
4.5
4.4
20
4.3
4.2
40
4.1
4.0
60
10
3.9
3.8
80
3.7
3.6
9
8
80
60
40
20
N=1.79
N=1.77
N=1.81
N=1.75
N=1.73
1
2
3
4
5
6
7
80
60
40
20
FeAl₂O₄
Hercynite
N=1.83 G=4.10?
MgAl₂O₄
Spinel
G=3.57 N=1.715

FIG. 2

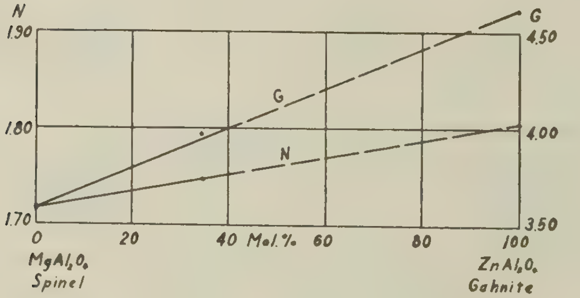
N
1.90
1.80
1.70
G
4.50
4.00
3.50
G
N
0
20
40 Mol.% 60
80
100
MgAl₂O₄
Spinel
ZnAl₂O₄
Gahnite

FIG. 3

Artificial spinel of gem quality has been made with varying amounts of excess Al_2O_3 (in crystal solution) up to 60 per cent. The limit seems to be about 68 per cent.[5] The relations between this variation in composition and the density and refractive index are shown in Fig. 4.

Many analyses point to the conclusion that $FeFe_2O_4$ in spinel can become Fe_2O_3 without destruction of the crystal structure, just as it can in magnetite. Accordingly, both Al_2O_3 and Fe_2O_3 can exist in the spinel crystal structure, though neither is possible in unlimited amount. Furthermore, this fact makes it reasonable to assume such changes of $2FeO$ to Fe_2O_3, or Fe_2O_3 to $2FeO$ as may be necessary to compute the spinel molecules from the analyses, and this assumption has been made in the computations.

Since the ferrites do not intercrystallize freely with the aluminates and chromates of the spinel group, they can be arranged on triangular diagrams, as shown in Fig. 5. All four end-members have been made artificially and it seems very probable that they can intercrystallize in all proportions at least in the two ternary systems which are shown, although this has not yet been demonstrated. Unfortunately the refractive indices are not well known in this system and no attempt is made to show them.

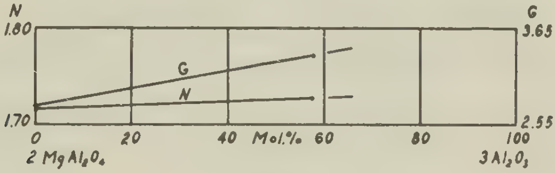

FIG. 4

Of course, it should be remembered in using these diagrams that the natural minerals usually contain still other constituents (notably TiO_2) and therefore the specific gravity may vary from that shown by the diagram.

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[5] Hägg, G., and Söderholm, G.: *Zeits. physik. Chem.*, *B*, **29**, 88 (1935).

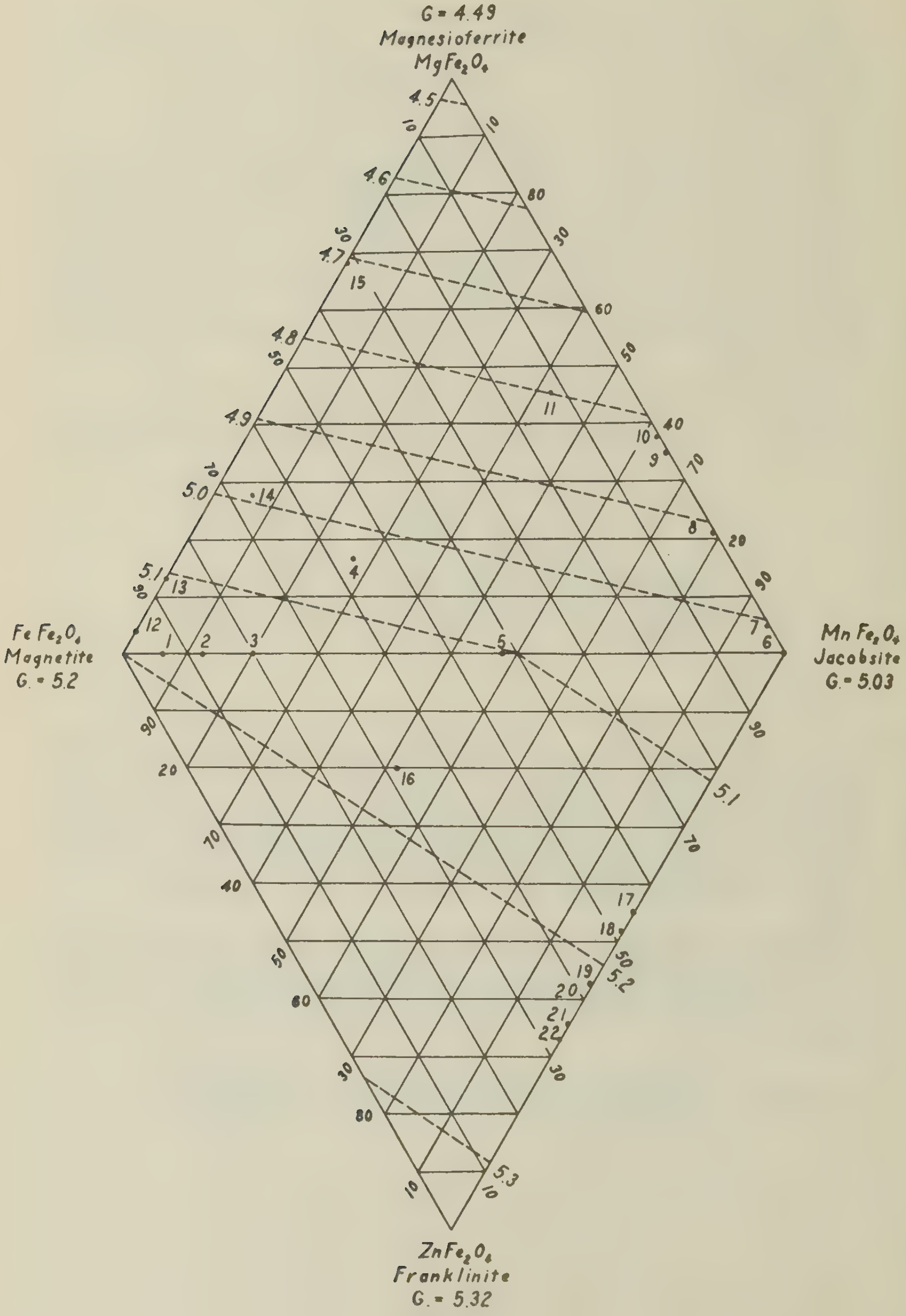
G = 4.49
Magnesioferrite
$MgFe_2O_4$
Fe Fe_2O_4
Magnetite
G. = 5.2
Mn Fe_2O_4
Jacobsite
G. = 5.03
$ZnFe_2O_4$
Franklinite
G. = 5.32
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.1
5.2
5.3
10
20
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

FIG. 5

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References for Figure 2

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7. "Ferropicotite," Haute Loire. A. Lacroix: *Mineral. France*, **4**, 306 (1910) (=22 of Fig. 1).
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References for Figure 5

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Many other analyses are given in *Trans. Sci. Res. Inst. Econ. Mineral, Fas.* **85** by S. A. Vakhromeev, J. A. Zimin, K. E. Kozhevnikov, A. N. Laskov and G. M. Mazaev: Chromite Deposits in the Urals, Moscow, 1936.

CRYSTALLOGRAPHIC NOTES: CAHNITE, STOLZITE, ZINCITE, ULTRABASITE

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Crystal Class of Cahnite

In the first description of cahnite by Palache and Bauer (1927) the mineral was stated to be tetragonal, sphenoidal in symmetry. No form in a general position was observed and the exact definition of the class was, therefore, not possible. This ambiguity no longer exists and it can be stated, on the basis of facts here presented, that cahnite belongs to the tetragonal disphenoidal class, $\bar{4}$. It is the first mineral found to belong to this crystal class, and the only hitherto recognized representative, a calcium aluminum silicate, was classified here only on the basis of etch figures.

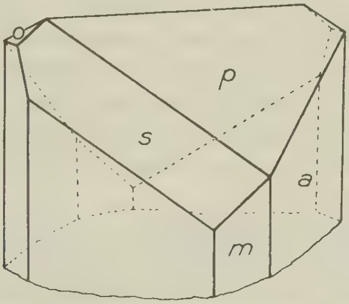

Fig. 1. Crystal of cahnite from Franklin, N. J., showing the prisms $a\{100\}$ and $m\{110\}$, and the disphenoids $p\{111\}$, $o\{1\bar{1}1\}$ and $s\{311\}$.

On his last visit to the Harvard Mineralogical Laboratory in 1935, Mr. Lazard Cahn brought with him a small specimen from Franklin, N. J., showing untwinned crystals of cahnite in small vugs in a mass of granular willemite. On these crystals Cahn had recognized the presence of a form modifying but two of the edges between {111} and {100}. A crystal was measured and the form was identified as {311}, with but two faces on the upper end of the crystal. This distribution of faces was confirmed on two other crystals and is shown in the accompanying figure.

	No. of	Measured		Range		Calculated	
Form	faces	ϕ	ρ	ϕ	ρ	ϕ	ρ
311	5	71°34′	62°50½′	71°22′–71°45′	62°33′–63°12′	71°34′	62°47½′

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* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 243.

The presence of this well-identified general form with the distribution of faces indicated leaves no doubt of the disphenoidal character of cahnite. It is a satisfaction to thus place on record the last scientific observation of Mr. Cahn upon the unusual mineral which he discovered and which bears his name.

STOLZITE FROM ARIZONA AND NIGERIA

Stolzite from Arizona

Two localities for the rare tungstate of lead, stolzite, were found in 1939 by Mr. Edwin Over and specimens were secured for the Harvard Mineralogical Museum. The mineral is so rare that any new occurrence of it, especially when in well-formed crystals, seems worthy of record. Both localities are active tungsten mines.

Primos Mine, near Dragoon, Arizona. The two specimens found were on the dump of the largest tunnel of the Boericke or Primos Mine. They come from a quartz vein which contains chalcopyrite, sphalerite, huebnerite, scheelite, fluorite and galena. In some cavities the sulphides had broken down and a coating of covellite was present. The stolzite crystals are in quartz vugs attached directly to the quartz. They are a millimeter or more in length and of a pale yellow color. The specific gravity was determined to be 8.26, the surest character by which they may be distinguished from wulfenite.

These crystals, very few in number, are highly complex. One of exceptionally symmetrical development was measured and showed the forms: $c\{001\}$, $n\{130\}$, $m\{110\}$, $e\{011\}$, $\delta\{113\}$, $p\{111\}$, $r\{441\}$,* $\sigma\{137\}$, $\pi\{133\}$. Of these forms the more important are shown in Fig. 2, in which $p\{111\}$ and $\pi\{133\}$ are dominant. The prism zone is strongly developed, but the faces of the prism forms are broken and reflect poorly. The terminal forms are very brilliant and give consistent readings for position as shown in Table 1. One form, $\sigma\{137\}$, is new and is present with all four faces. Pough (1937) has reported this form on powellite from Tonapah, Nevada. The forms $\delta\{113\}$ and $r\{441\}$ are weak forms and are not figured as they are minute on the crystal. $\{113\}$ was first reported by Artini (1905) from Sardinia; $\{441\}$ was found by Hodge-Smith (1934) to be characteristic of crystals of different habits from the South Mine, Broken Hill, Australia. The calculated angles of Table 1 are based on the elements of Hlawatsch (1897), which are confirmed by the results of this study.

Reef Mine, Huachuca Mts., south of Tombstone, Arizona. The stolzite crystals are implanted on the walls of angular cavities in vein quartz from which sulphides have been weathered out. Elsewhere the vein contains scheelite, as well as galena, chalcopyrite, pyrite and limonite. The vein was originally worked for free gold, but the tungsten content is now the main value.

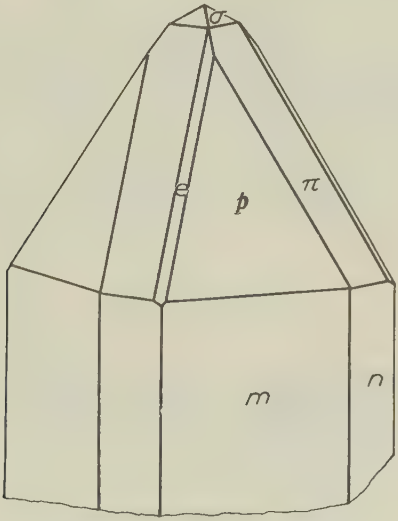

FIG. 2. Crystal of stolzite from Primos Mine, Arizona, showing the prisms _m_{110} and _n_{130} and the dipyramids _e_{011}, _p_{111}, σ{137} and π{133}.

The 1–2 mm. crystals are pale yellow and are of very varied habit due to the varying relative development of the forms: _c_{001}, *_f_{320}, _m_{111}, _p_{111} and *_z_{121}. Figures 3 and 4 show the two common variations; pseudocubic crystals are also rarely present. The new form {121} is well established by the measurements. It is known on wulfenite as is the more doubtful new prism {320}. The base {001} is rarely bright; more often it is dull and in some cases seems to have been etched to a hopper form. {111} is always very brilliant, as are the much smaller faces of {121}. The prism {320} is rounded as it so often is in wulfenite. Its nature, however, is easily apparent in the skew intersections it makes with the pyramid, and the few measurements obtained indicate a position about that indicated by the symbol.

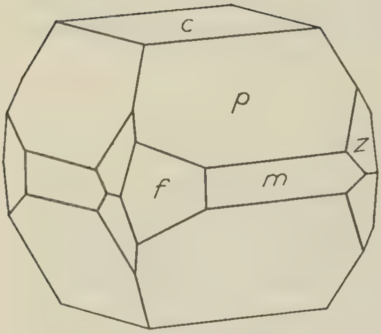

FIG. 3. Crystal of stolzite from Reef Mine, Arizona, showing $c\{001\}$, the prisms $m\{110\}$ and $f\{320\}$ and the dipyramids $p\{111\}$ and $z\{121\}$.

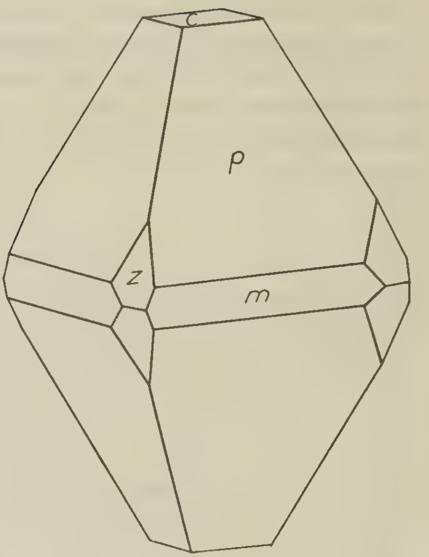

FIG. 4. Crystal of stolzite from Reef Mine, Arizona, showing $c\{001\}$, $m\{110\}$, $p\{111\}$ and $z\{121\}$.

TABLE 1. ANGLES OF STOLZITE

Forms	No. of faces	Measured		Range		Calculated	
		φ	ρ	φ	ρ	φ	ρ
*320	3	34°00′	90°00′	33°31′–34°30′	— — —	33°41½′	90°00′
011	4	0 13	57 29½	0 08 – 0 22	57°16′–57°56′	0 00	57 21
111	12	44 56	65 39	44 30 –45 05	65 30 –65 45	45 00	65 37½
113	4	45 04	36 29	44 57 –45 05	36 17 –36 40	45 00	36 20½
441	2	45 10	84 10	44 42 –44 56	83 45 –84 36	45 00	83 32
133	4	18 45	58 48	18 23 –19 02	58 43 –58 54	18 26	58 42½
*137	4	18 34	35 20	18 30 –18 45	35 17 –35 22	18 26	35 11
*121	4	26 30	74 05	26 17 –26 40	73 54 –74 20	26 34	74 00½

* New forms.

Stolzite from Nigeria

Ward's Natural Science Establishment of Rochester, New York, has recently supplied the Harvard collection with a sample of stolzite from the tin fields of Abuja, northern Nigeria. It is obviously a placer product, as the larger crystals, up to 3 mm. in diameter, are well rounded. But the smaller crystals, averaging about 1 mm. through, are, many of them, still sharp and brilliant. The color varies from lemon to orange-yellow and the sample seems to be very pure. The specific gravity of three separate crystals was determined on the Berman microbalance, giving an average value of 8.34±0.004, a value considerably higher than any hitherto published for this mineral. The calculated density is 8.45. Crystals were measured which showed the forms: *c*{001}, *e*{011}, *ϵ*{021}, *p*{111}, and *π*{133}. The base is dull, often very small and the crystals are pyramidal after either *e* or *p*. {021} forms narrow truncations of the basal edges of *e* when it is dominant. Prisms seem to be absolutely lacking and *π* is indicated by faint lines of striation between *e* and *p* on one side only, the only visible evidence of hemihedrism. The figure shows a characteristic combination and habit.

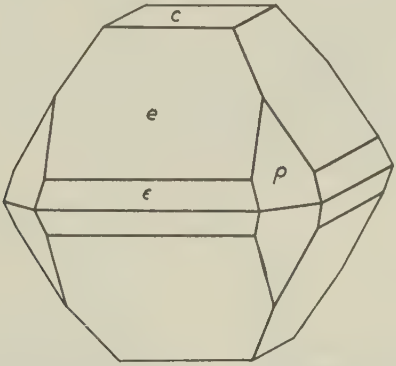

Fig. 5. Crystal of stolzite from Abuja, Nigeria, showing *c*{001}, *e*{011}, *ϵ*{021} and *p*{111}.

Notes on Zincite

Crystals of zincite are so infrequent in the only important place of occurrence—Franklin, N. J.—that any new find of them seems worthy of record and particularly so when they occur in a new form. Some time ago Mr. L. H. Bauer sent to the Harvard Mineralogical Laboratory a small specimen of ore containing a vug lined with colorless fluorite and a few crystals of pale yellow zincite. These were in part aggregated into spheroidal groups, but a few stood isolated on the wall of the cavity. Measurement of one of these millimeter-wide crystals showed it to present only the pyramid $\{10\bar{1}3\}$, a form previously only known on artificial crystals of zinc oxide. Figure 6 shows one of these crystals in the familiar peg-top form but much flatter than the ordinary Franklin crystal.

Measured ρ 31°45′ Calculated ρ 31°25′

The fluorite crystals are also minute, clear and colorless and show a rare combination for this mineral, the forms present being *d*{011}, *a*{001} and *m*{113}. Minute amounts of fibrous white willemite and of a soft micaceous clay-mineral not more exactly determined, were also present.

With this specimen Mr. Bauer also sent a superb specimen of very brilliant orange-colored zinc oxide, which he had received from Professor R. Norris Shreve of Purdue University. Professor Shreve, at the writer's request, secured the following statement as to the conditions under which these crystals were formed. It is written by Robert Ammon, Chief Metallurgist of the American Zinc Company of Illinois at St. Louis.

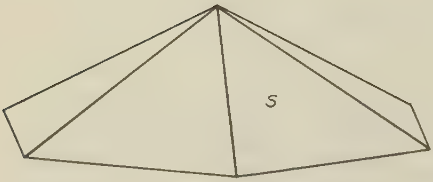

FIG. 6. Crystal of zincite from Franklin, New Jersey, showing $c\{000\bar{1}\}$ and $s\{10\bar{1}3\}$.

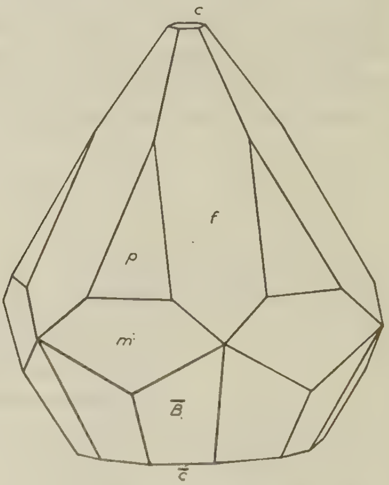

FIG. 7. Crystal of artificial zinc oxide showing $c\{0001\}$ and $\bar{c}\{000\bar{1}\}$, the hexagonal pyramids $f\{11\bar{2}2\}$ and $p\{10\bar{1}1\}$ and the negative dihexagonal pyramid $\bar{B}\{21\bar{3}\bar{3}\}$.

> In regard to the zincite crystals, the only information we have on these is that they were found in the combustion laboratory of a furnace operating on the production of French oxide. This furnace is oil fired, contains four carborundum retorts, each of which is fed with a supply of molten zinc in one end and the zinc vapor leaves the other end and is burned to ZnO. This furnace operates with an average temperature in the combustion laboratory of 1240° C. Our metallurgist at Hillsboro believes the combustion gases are oxidizing and the formation of these crystals starts with a small leak in the carborundum retort, through which a small amount of metallic zinc penetrates. His observation is that if a leak has been present for say 50 to 70 days, then, due to the exposure for so long a time at such a high temperature, this red crystal is formed.

The crystals, which are very brilliant, are of varying habits. Most of them are attached at the lower extremity and show on the free end a slender prism of the first order together with the first order unit pyramid $p\{10\bar{1}1\}$, more or less modified by the truncating pyramid of the second order $f\{11\bar{2}2\}$. Tiny facets of the pedion $c\{0001\}$ are also generally present. A few crystals, however, are so attached as to show both terminations, and the lower end presents a perfectly regular development of the dihexagonal pyramid $\{21\bar{3}\bar{3}\}$ truncated in some crystals by a large and particularly brilliant face of the lower pedion $\bar{c}\{000\bar{1}\}$. This pyramid has heretofore been observed but once, by von Rath, whose crystals showed only one termination which he accordingly represented as belonging to the upper end. Since the two pyramids which in our crystals bound the positive end are the commonest positive forms on zinc oxide, we have no choice but to consider the dihexagonal form as negative, a choice confirmed by the larger development of the negative pedion which is a common character. Figure 7 shows these forms with an average development. Where the negative pedion is small the perfectly regular development of this complex form in opposition to the positive end with its two nearly equant hexagonal pyramids and a very slight development of the prism makes a new and striking habit of hemimorphism never hitherto figured.

The following angles establish the nature of the forms found on these crystals:

	Measured		No. of faces	Calculated (for $c = 1.6077$)	
	ϕ	ρ		ϕ	ρ
$10\bar{1}1$	30°00′	62°36′	4	30°00′	61°41½′
$11\bar{2}2$	0 00	58 08	2	0 00	58 07
$12\bar{3}3$	10 53	58 37	9	10 53½	58 35

New determinations of the density of zinc oxide were made with the microbalance on the material described below. Natural crystal fragments of zincite from Sterling Hill, N. J. (Berman, *Am. Mineral.*, **12,** 168, 1927) gave a density of 5.66 ± 0.02 (4 determinations). The artificial zinc oxide of this paper gave a density of 5.665 ± 0.02 (3 determinations).

ULTRABASITE IDENTICAL WITH DIAPHORITE

Ultrabasite was described by Rosický and Sterba-Böhm (1920) as an orthorhombic mineral with the composition $Pb_{28}Ag_{22}Sb_4Ge_3S_{53}$. The few samples known came from the Himmelsfürst shaft at Freiberg, Saxony.

In reviewing this work, Dr. Berman found that by transforming to a different unit cell, the forms and angles were essentially identical with those of diaphorite. Transformation, ultrabasite to diaphorite, 200/040/00½. The values are listed in the following table.

	Ultrabasite Calculated			*Diaphorite* Calculated	
	ϕ	ρ		ϕ	ρ
210	63°42⅓′	90°00′	*110	63°39′	90°00′
110	45 20½	90 00	*120	45 16	90 00
230	34 03½	90 00	*130	33 56	90 00
130	18 14	90 00	160	18 36	90 00
015	0 00	16 18	(045)	(0 00)	(16 24)
012	0 00	36 10⅓	*041	0 00	36 21
011	0 00	55 38	*081	0 00	55 48½
102	90 00	36 30	*201	90 00	36 36½
101	90 00	55 57	*401	90 00	56 03½
114	45 20½	27 28¾	(121)	(45 16)	(27 26½)
214	63 42⅓	39 35¾	*221	63 39	39 39½
218	63 42⅓	22 25⅓	*111	63 39	22 31
126	26 50½	28 38¾	283	26 47	28 47½

Parentheses indicate that the form is not known on diaphorite.
* Common forms.

The specific gravity and other physical properties of the two minerals also agree. I wrote to Professor Rosický informing him of these facts and asked for type material for testing. A sample finally reached us with the statement that it yielded a spectroscopic evidence of the presence of germanium. The specimen was part of a crystal with all the appearance of diaphorite. The only visible impurity was a small amount of galena. A sample free from galena was examined by Mr. Kent, in the large two-meter, quantitative grating spectrograph of this laboratory, and gave no trace of Ge, although a similar test on germanite gave the line of Ge. Under these circumstances one can only conclude that the analysis on which ultrabasite was defined must have been made on a different substance from that used for the morphologic and physical characters. The name, therefore can only be employed as a synonym for diaphorite.

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HLAWATSCH, C., *Zeits. Krist.,* **29,** 130 (1897).
HODGE-SMITH, T., *Records Australian Mus.,* **19,** 166 (1934).
POUGH, F. H., *Am. Mineral.,* **22,** 57 (1937).
ROSICKÝ AND STERBA-BÖHM, *Zeits. Krist.,* **55,** 430 (1920).

FLUORESCENT SODALITE AND HACKMANITE FROM MAGNET COVE, ARKANSAS[1]

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Abstract

Two varieties of fluorescent sodalite are found in the tinguaite rocks of Magnet Cove, Arkansas: a blue sodalite that fluoresces a purplish-blue to violet-red, and a white variety, hackmanite, which strongly fluoresces a reddish-orange. The hackmanite also exhibits the peculiar phenomenon of evanescence; that is, change of color from rose to colorless and back again with alternate exposures to light and darkness. It shows also the property of photosensitivity; that is, the phenomenon of induced reappearance of the rose color by exposure to ultra-violet radiation and the disappearance of the color in daylight.

OCCURRENCE

Magnet Cove, or "The Cove" as it was known to the early travelers, is situated in Hot Spring County, about 12 miles east of Hot Springs, in southwest-central Arkansas, near the boundary between the Coastal Plain Province and the Ouachita Plateau. The igneous complex at Magnet Cove occupies an area of about 5 square miles and is elliptical in shape. It is basin-like in form due to an encircling rim of the more resistant peripheral zone of intrusive rocks around a depression left by erosion of the softer rocks in the center. The igneous rocks belong mostly to the nepheline-syenite group, and were intruded—apparently in Upper Cretaceous time—into closely folded Paleozoic sedimentary rocks, novaculite, sandstone, and shale.

There are exposures of several different types of alkalic rocks; including nepheline-mica syenite, nepheline syenite dike rock, nepheline tinguaite, leucite tinguaite, and alkalic pegmatite with which are associated a large group of minerals. Among these is natural lodestone which gives Magnet Cove its name.

A comprehensive description of the petrology and geology of Magnet Cove is contained in the classical work of J. Francis Williams.[2] The petrogenesis of Magnet Cove is discussed in an article by H. S. Washington,[3] and a paragenetic classification of the Magnet Cove minerals has been made by K. K. Landis.[4] A brief account of the geomorphology and regional geology is given by Landis, Parks, and Scheid.[5]

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[1] Published by the permission of the Director, U. S. Geological Survey, Department of the Interior, Washington, D. C.

[2] Williams, J. Francis, The igneous rocks of Arkansas: vol. **II**, *Annual Report of the Geological Survey of Arkansas for 1890.*

[3] Washington, H. S., Igneous complex of Magnet Cove, Arkansas: *Bull. Geol. Soc. Am.*, **11**, 389–416 (1900).

Microscopic grains of sodalite were recognized in thin sections of rocks from Magnet Cove by Williams[6] and by others, but recent quarry operations revealed the first material visible to the unaided eye. Specimens of blue sodalite and the evanescent white variety hackmanite, were first obtained through Lawton D. Kimzey and Joe W. Kimzey by Hugh D. Miser during his visit to Magnet Cove, Arkansas, in 1936. Much additional material has been obtained since—some from Lawton D. Kimzey, and the remainder during visits to the locality in 1937 by Lawton D. Kimzey, Hugh D. Miser, C. S. Ross, and W. T. Schaller; and in 1938 by Jewell J. Glass and Mr. Kimzey. This is believed to be the first occurrence of hackmanite to be identified in the United States.

The sodalite and the variety hackmanite occur in two quarry pits opened by Joe W. Kimzey on the south border of Magnet Cove about three-fourths of a mile northeast of Cove Creek Station and about one and a half miles southwest of Magnet Post Office. One pit is 60 feet long in an east-west direction, and as much as 35 feet wide and 12 feet deep, and the other 100 feet east of the first, is 50 feet long in a southeast-northwest direction, 10 feet wide and 6 feet deep. The rock of the area is a fine-grained dark greenish-gray dike type of tinguaite. At this locality the tinguaite contains a few widely separated irregular masses and veins of sodalite and hackmanite, varying from small white specks to masses as much as 4 inches in diameter. Another occurrence of similar material has been discovered by Lawton D. Kimzey on the north side of the Cove 2 miles northwest of the first locality, and was visited by Miss Glass and Mr. Kimzey in 1938.

The hackmanite variety of sodalite is another addition to the increasing list of minerals from Magnet Cove. Taeniolite, a rare mica, was recently described by Miser and Stevens,[7] molybdenite has just been reported,[8] and a crystal of emerald-green sphalerite about 4 mm. in diameter emplanted in a cavity on a felted mass of dark brown acmite with aegirite and orthoclase was collected recently by Russell S. Henderson of the U. S. Forest Service.

The blue sodalite occurs either alone in lenses, or as rounded or irregular masses, or more commonly in close association or as an intergrowth with hackmanite, similar to the occurrence from Kishengarh State, Rajputna, India, described by Vredenburg[9] in 1904, and from Kola Peninsula, U.S.S.R., by Fersman[10] in 1926.

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[4] Landis, Kenneth K., A paragenetic classification of the Magnet Cove minerals: *Am. Mineral.*, **16**, [No. 8], 313 (1931).

[5] Landis, K. K., Parks, Bryan, and Scheid, Vernon E., Mining districts of the eastern states: *XVI International Geol. Congress, Guidebook* **2**, *Excursion A-E.*

[6] Williams, J. F., *op. cit.*

[7] Miser, H. D., and Stevens, R. E., Taeniolite from Magnet Cove, Arkansas: *Am. Mineral.*, **23**, [No. 2], 104 (1938).

[8] Sleight, V. G., Molybdenite at Magnet Cove, Arkansas: *Am. Mineral.*, **26**, 132 (1941).

The blue sodalite contains pyrite, calcite, black biotite, and purple fluorite which sometimes forms a rim around the edges. The most common alteration product of the blue sodalite is thomsonite. The colorless sodalite (hackmanite) in general is free from inclusions, only a little intergrown calcite having been noted. The hackmanite is usually surrounded by a zone of blue sodalite interspersed with patches of white hackmanite or intimate intergrowth without distinguishable boundaries (Fig. 1).

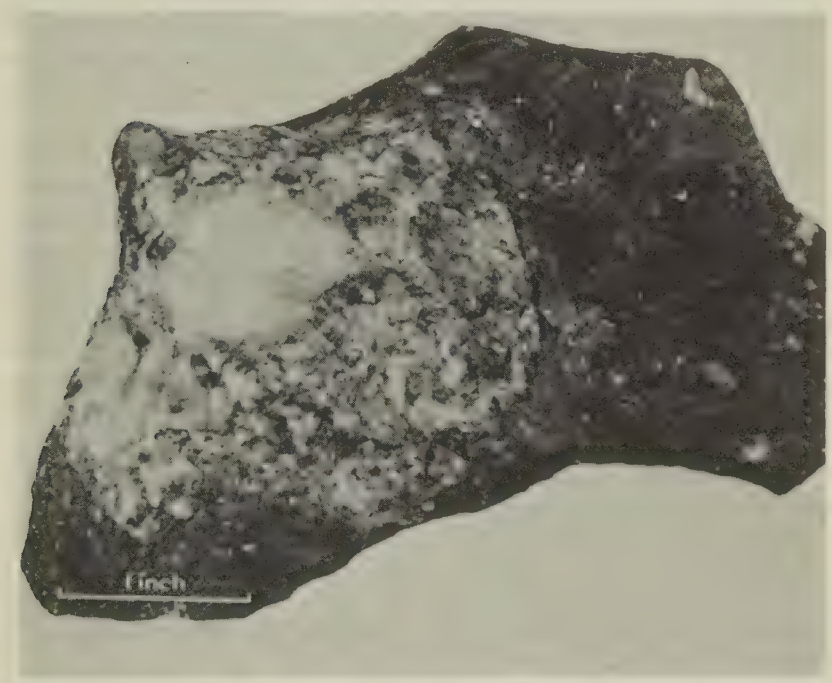

Fig. 1. Photograph showing a sodalite-hackmanite mass in tinguaite dike rock from Kimzey quarry, Magnet Cove, Arkansas. The white almost circular center is evanescent hackmanite surrounded by a mottled zone of blue sodalite interspersed with patches of hackmanite. Both minerals are fluorescent. Scale in inches.

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[9] Vredenburg, E., Elaeolite and sodalite-syenite in Kishengarh State: *Records of Geol. Survey of India*, **31,** 43–44 (1904).

[10] Fersman, A. E., Minerals of the Kola Peninsula: *Am. Mineral.*, **11,** [No. 11], 289–299 (1926).

FLUORESCENCE AND EVANESCENCE

Sodalite was discovered and named by Dr. Thomas Thomson[11] at Edinburgh in 1810. The material was obtained from Mr. Thomas Allan, who had purchased a collection of minerals from west Greenland. Dr. Thomson gives the following description of the original material: "Sodalite occurs in a primitive rock mixed with sahlite (diopside-hedenbergite), augite, hornblende, and garnet. It occurs massive, and crystallized in rhombic dodecahedrons. Its colour is intermediate between celandine and mountain green . . . particles of [green] sahlite doubtless modify the colour. . . . No mineral has hitherto been found containing nearly so much soda as this, hence the reason for the name by which I have distinguished it."

Dr. Thomson makes no mention of the color change of the sodalite from Greenland. Robert Allan,[12] the son of Thomas Allan, however, states in his *Manual of Mineralogy*, published in 1834, that the mineral from West Greenland "is associated with feldspar, arfvedsonite, eudyalite, and augite, . . . its colour is green unless newly fractured, when it presents a brilliant pink tinge, but this on exposure to light goes off in a few hours." Since this is the material analyzed by Dr. Thomas Thomson and named sodalite by him, the original sodalite was evanescent, and was no doubt the same variety of sodalite as that described later from Kola and given the name hackmanite by Borgström.[13]

No color change was noted in the fluorescent sodalite from New Jersey and from New Hampshire described by Smith.[14]

Under ultra-violet light the blue sodalite from Magnet Cove fluoresces a purplish-blue to violet-red; but it is the white hackmanite that displays a magnificent show of fluorescence, glowing so brightly that the duller fluorescence of the blue sodalite can hardly be seen. The fluorescence is bright golden-yellow under a Nico lamp, deep rose to reddish-orange under some mercury vapor lamps, firefly-yellow under the iron arc, and pink under the argon lamp. No phosphorescence nor thermoluminescence was noted.

The white hackmanite, in addition to its spectacular fluorescence, also shows the phenomenon of evanescence. By daylight it is white and translucent to colorless and transparent. Some of these specimens when kept in the dark for two or three weeks assume a lilac-rose color which disappears rapidly (within two minutes) on exposure to daylight and almost instantly in direct sunlight. The restoration of the rose color is greatly accelerated by exposure to ultra-violet rays. Exposed to ultra-violet rays for two to five minutes the colorless hackmanite assumes a brilliant lilac-rose color which fades rapidly in daylight. The color seems to reappear more completely in some of the specimens than in others and not at all in some.

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[11] Thomson, Thomas, Chemical analysis of sodalite, a new mineral from Greenland: *R. Soc. Ed. Tr.*, [6], **5,** 387 (1810).

[12] Allan, Robert, *A Manual of Mineralogy*, Edinburgh, **1834.**

[13] Borgström, L. H., Hackmanit ett nytt mineral i sodalitgruppen: *Geol. För. Stockholm*, **23,** 563 (1901).

[14] Smith, Lawrence L., Fluorescent sodalite: *Am. Mineral.*, **22,** [No. 4], 304 (1937).

The induced color change of hackmanite when exposed to ultra-violet light was first observed by O. Ivan Lee[15] on hackmanite from Bancroft, Ontario, which changed from pink to a raspberry shade or deep violet on exposure to ultra-violet light. The induced color faded rapidly and nearly completely on exposure to a strong light.

Hackmanite from a sodalite-aegerite rock (tawite) from Kola Peninsula, Lapland (U.S.S.R.) was described as a new variety of sodalite by Borgström.[16]

At nearly the same time (work published in 1904) Vredenburg,[17] who was working in India, discovered a peculiar sodalite which exhibited a bright red color on the freshly broken surface of the rock in which it occurred. He observed that the red color disappeared rapidly on being exposed to bright daylight and that the colorless mineral then would resume a pink color when kept in darkness for a fortnight or three weeks. This phenomenon, he stated, had not previously been recorded for any mineral.

The third recorded occurrence of this peculiar variety of sodalite is at Bancroft, Ontario, and was described by Walker and Parsons[18] in 1925, who proposed the term "evanescent" to describe this color change. The evanescent hackmanite at Bancroft is associated with cancrinite, nepheline, and calcite as it is at the other three localities. An occurrence of the hackmanite variety of sodalite from Korea is described by Iwase,[19] and an unrecorded occurrence of hackmanite has been observed in the Ice River region in British Columbia.[20]

The fluorite and calcite associated with the sodalite from Magnet Cove are both thermoluminescent. When heated, the fluorite (chlorophane variety) glows with a yellowish-green color, and the calcite, like all the calcite from Magnet Cove that was tested, emits a brilliant yellow, almost flame-colored light.

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[15] Lee, O. Ivan, A new property of matter: Reversible photosensitivity in hackmanite from Bancroft, Ontario: *Am. Mineral.*, **21**, [part 1, No. 12], 764–776 (1936).

[16] Borgström, L. H., Hackmanit ett nytt mineral i sodalitgruppen: *Geol. För. Stockholm*, **23**, 563 (1901).

[17] Vredenburg, E., Elaeolite and soda syenites in Kishengarh State, Rajputana, India: *Records of Geol. Survey of India*, **31**, 43–44 (1904).

[18] Walker, T. L., and Parsons, A. L., Evanescent pink sodalite or hackmanite from Bancroft, Ontario: *Am. Mineral.*, **10**, [No. 3], 66 (1925).

[19] Iwase, Ei-ichi, Über die photochemischen Eigenschaften des Sodaliths von Kisshu, Korea: *Zeits. Krist.*, **99**, 314 (1938).

[20] Personal letter from Dr. A. L. Parsons.

PROPERTIES

All of the sodalite collected at Magnet Cove is massive, but a few traces of hexagonal outline were observed under the microscope. The sodalite is seen to contain numerous dust-like inclusions. The bright blue sodalite has a specific gravity of 2.278 and index of refraction of 1.483. The white or colorless hackmanite has a specific gravity of 2.287 and index of refraction of 1.487, and frequently shows weak birefringence probably due to strain.

COMPOSITION

An analysis of the deep blue sodalite from Magnet Cove is shown in column I of Table 1. For comparison, the analysis of the blue sodalite from India, associated with the evanescent hackmanite, is given in column II, and of the original green sodalite from Greenland in column III.

A sample of the purest, more transparent, and colorless hackmanite from Magnet Cove was analyzed with the following results, column I, Table 2. When dissolved in dilute hot hydrochloric acid, H_2S was evolved, showing the presence of a sulphide. For comparison the analysis of hackmanite from the Kola Peninsula is given in column II, and of that from Bancroft, Ontario, in column III.

Table 1. Blue Sodalite from Magnet Cove, Arkansas (I), Compared Chemically With Blue Sodalite Associated With Hackmanite from Rajputana, India, and With the Original Sodalite from Greenland.

	I	II	III	
	Magnet Cove, Ark.	Rajputana, India	Greenland	
SiO_2	36.36	38.055		38.52
Al_2O_3	32.09	31.300		27.48
Fe_2O_3	0.07	trace		—
FeO	none	—		—
TiO_2	none	—		—
MnO	0.06	—		—
MgO	none	—		—
Na_2O	24.73	24.77		23.50
K_2O	0.12	—		—
H_2O–110° C.	0.12	0.82	loss on ign.	1.70
H_2O+110° C.	0.86			
Cl	6.79	7.18	muriatic acid	3.00
S	none	—		
SO_3	trace	trace	volatile matter	2.10
$CaCO_3$[1]	0.50	0.001 (CaO)		
	101.70			100.00
Less oxygen equiv. for Cl	1.53	1.618		
Total	100.17	100.508		
Sp. gr.	2.278[2]	2.27		2.378

I. Blue sodalite from Magnet Cove, Arkansas. J. J. Fahey, analyst.

II. Blue sodalite from Rajputana, India. E. Vredenburg, analyst.

III. Green sodalite from Greenland. Thomas Thomson, analyst.

[1] Identified as calcite in thin section.

[2] Sp. gr. determined by the Berman precision balance.

TABLE 2. ANALYSIS OF HACKMANITE FROM MAGNET COVE, ARKANSAS (COLUMN I), COMPARED WITH THE ORIGINAL ANALYSIS OF THE HACKMANITE FROM KOLA PENINSULA (COLUMN II), AND WITH HACKMANITE FROM BANCROFT, ONTARIO, CANADA (COLUMN III).

	I Magnet Cove, Ark.	II Kola Peninsula, U.S.S.R.	III Bancroft, Ont.
SiO_2	36.70	36.99	37.08
Al_2O_3	32.01	31.77	32.58
Fe_2O_3	0.07	0.17	—
FeO	none	—	—
TiO_2	none	—	—
MnO	none	—	trace
MgO	none	none	0.03
Na_2O	24.79	25.84	22.26
K_2O	0.17	0.16	.53
H_2O–110° C.	none	—	0.67
H_2O+110° C.	0.36	—	
Cl	7.00	6.44	6.82
S	trace	0.39	—
SO_3	trace	—	—
$CaCO_3$[1]	0.29	—	(CO_2) 0.32
	101.39	101.81	100.79
Less oxygen equiv. for Cl	1.58	1.64	1.53
Total	99.81	100.17	99.26
Sp. gr.	2.286[2]	2.32–2.33[3]	

I. Hackmanite from Magnet Cove, Arkansas, J. J. Fahey, analyst.

II. Hackmanite from Kola Peninsula. L. H. Borgström, analyst.

III. Hackmanite from Bancroft, Ontario, Canada. H. C. Rickaby, analyst.

[1] Identified as calcite.

[2] Specific gravity determined on the Berman balance.

[3] Specific gravity 3.32 to 3.33 originally given is a misprint. In a letter from Leon H. Borgström, dated Nov. 20, 1925, written to Prof. T. L. Walker, Toronto, he says, "We made a new determination of the specific gravity of this mineral and found 2.33 (not 3.33). 3.33 is a misprint."

The analyses show that the two varieties of sodalite at Magnet Cove have almost the same chemical composition. A trace of sulphide was found in the hackmanite and none in the blue sodalite, which, however, contains a small quantity of manganese. The specific gravity of the two varieties is nearly the same. A comparison of the analyses of the variously colored sodalites (blue, pink, and colorless) shows that the composition is essentially the same; that is, the variation between the different colored varieties is no greater than the variation in different analyses for the same colored varieties. The assumption that manganese is probably accountable for the evanescent phenomenon does not hold for the Magnet Cove hackmanite which shows none.

The most noticeable difference aside from the color change is the difference in index of refraction. The blue sodalite from Magnet Cove shows $n=1.483$, and for hackmanite $n=1.487$. A study of the indices of refraction for sodalities made by Iwase[21] shows that the colorless and blue varieties have consistently $n=1.483$, and that the rose colored (hackmanite) variety has $n=1.485$ to 1.487. It is difficult to account for this constant difference in indices on the basis of the chemical analyses alone.

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[21] Iwase, *op. cit.*

X-RAY CRYSTALLOGRAPHY OF SEAMANITE

DUNCAN MCCONNELL, *Bureau of Mines, U. S. Department of the Interior, Washington, D. C.*, AND WALTER L. PONDROM, JR.,
The University of Texas, Austin, Texas

The description of seamanite, a hydrated manganese borate-phosphate, was presented by E. H. Kraus, W. A. Seaman, and C. B. Slawson in 1930.[1] During the succeeding decade, seamanite has not been reported from a second locality nor has the work of Kraus, Seaman, and Slawson been supplemented by an investigation employing *x*-ray methods. This paper will present certain new data on the crystallography of this mineral.

The crystals used in the present work came from the Chicagon mine, near Iron River, Michigan. They show the prism {110} and the pyramid {111}. None of the crystals had terminal faces at both ends and, consequently, the crystal class could not be decided in terms of the morphology.[2] Inasmuch as the *x*-ray method does not yield a unique determination of the probable space group, etching experiments were undertaken.

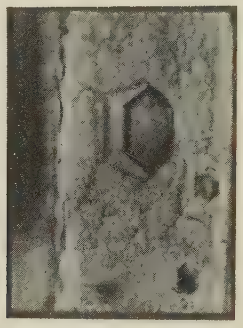

FIG. 1. Typical etch figures obtained on the prism face of seamanite indicating the symmetry plane (001). The edge to the left is [001]. Magnified 200×.

When treated with dilute HCl for a few minutes, etch figures were readily obtained on the prism faces. One of the typical figures resulting from this treatment is shown as Fig. 1. This indicates the existence of a symmetry plane parallel to (001) and, consequently, holohedral symmetry.

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[1] Kraus, E. H., Seaman, W. A., and Slawson, C. B., Seamanite, a new manganese phospho-borate from Iron County, Michigan. *Am. Mineral.*, **15**, 220–225 (1930).

[2] Kraus, Seaman, and Slawson state that seamanite is orthorhombic holohedral, but they do not mention observing terminations at both ends of the crystals, nor do they mention any other evidence to substantiate this conclusion.

Seamanite was investigated by Weissenberg and powder diffraction methods employing unfiltered iron radiation. The Weissenberg photographs showed the absence of $0kl$ reflections with k odd and $h0l$ with $h+l$ odd, but hkl and $hk0$ reflections of all sorts were present. Thus the probable space group is $Pbnm - V_h^{16}$.

The lattice constants, a_0 and b_0, were determined directly by rotation about the c-axis, using a number of $hk0$ reflections as well as pinacoidal reflections, in a camera with $r = 57.3$ mm. The value of c_0 was determined indirectly from Laue photographs made parallel to the a and b-axes. This technique was employed because of the needle-like habit of the crystals. The results obtained are as follows.

Absolute	Ratios	Ratios (K. S. & S.)
$a_0 = 7.83$ Å	0.517	0.519_5
$b_0 = 15.14$	1	1
$c_0 = 6.71$	0.443	0.450_8
(All ± 0.02 Å)		

The calculated density based upon these cell edges and the composition $4\,[Mn_3(PO_4)(BO_3)\cdot 3H_2O]$ is [3]

$$\rho = \frac{4 \times 372.6 \times 1.65}{7.83 \times 15.14 \times 6.71} = 3.09$$

This theoretical density disagrees with the specific gravity previously reported (3.128)[4] but it agrees with a determination made by us through the use of several small crystals and Thoulet's solution, 3.08 (4° C).

Kraus, Seaman, and Slawson suggested the probable isomorphism of seamanite and reddingite on account of the similarity of the axial ratios and the supposed chemical similarity. However, a powder diffraction pattern of reddingite, from Buckfield, Maine, is quite different from that of seamanite and this indicates that these minerals are not isostructural.

Acknowledgments

The x-ray tube with iron target was provided by a grant-in-aid from the Society of Sigma Xi. Additional assistance was provided by the [Texas] University Research Institute. The specimens of seamanite and reddingite were supplied by the U. S. National Museum through the kindness of Dr. William F. Foshag.

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[3] For the purpose of the calculation of the density, equal molecular amounts of P_2O_5 and B_2O_3 have been assumed. This is not strictly in accord with Slawson's analysis, in which a slightly greater amount of B_2O_3 was indicated. The use of the actual determinations would yield a calculated density slightly lower.

[4] This value becomes 3.12 if it is assumed that the measurements were made at 20° C. and that no temperature correction was applied.

NOTES AND NEWS

OBSERVATION OF CLAY MINERALS USING THE ELECTRON MICROSCOPE

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Research Laboratory, Matsuda Division, Tokyo Shibaura Electric Co.

Recently it has been shown that the electron microscope is a very valuable tool of research because of its enormous resolving power, and it opens up a new world, a world of infinitely small objects whose existence could only be surmised with the ordinary microscope.

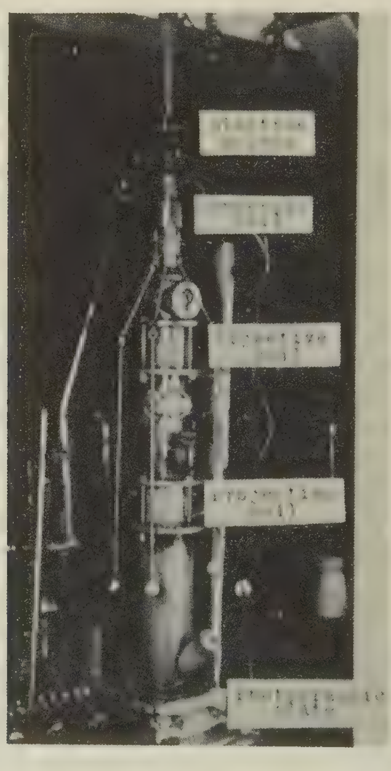

Fig. 1

All of the present methods, such as the use of ultra-violet light or oil immersion, increase the resolving power of the microscope, but even under the most favorable conditions to distinguish between objects separated by less than 0.1 micron is not possible. The writer has constructed an electron microscope and was able to obtain images with a magnification of 1000 diameters (maximum magnification of 10,000). Figure 1 shows the general construction of the apparatus.

The electron microscope is similar in principle to the ordinary microscope in which electro-magnetic coils replace the ordinary glass lenses of the latter, and the light source is now replaced by an electron source. The necessary high vacuum is maintained in the microscope by a four stage mercury diffusion pump. The object chamber allows the introduction of specimens into the evacuated microscope and their withdrawal without breaking the vacuum. The specimens to be observed are supported on a thin celluloid film which is made from an amylacetate solution.

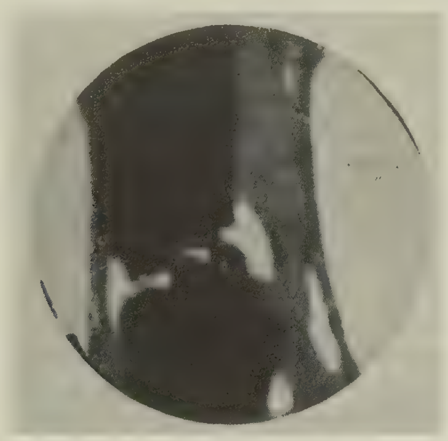

FIG. 2

Kibushi clay is a very plastic ceramic clay in Japan and its chemical composition is similar to that of kaolinite. At the same time, it is a noticeable property that it contains a small quantity of organic material. The appearance of Kibushi clay as observed under the electron microscope is illustrated by Fig. 2. In the illustration, definite crystal forms are not observed but a semi-transparent membrane supporting aggregations of grains may be seen. This membrane is quite different from the celluloid film supporting the specimen, because of its difference in electron transmissibility. The membrane is composed perhaps of organic material which is present in the Kibushi clay. But we cannot determine the character of the membrane from the photograph. In pure kaolinite, definite crystal forms are recognized and the membrane is absent.

THE GROSSULAROID GROUP (HIBSCHITE, PLAZOLITE)

D. S. Belyankin and V. P. Petrov,
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Recently the authors published two short articles on hibschite,[1,2] which was first described by Cornu (1905, 1906, 1907) and found in Bohemia (Upper-Turan contact marls of Marienberg and Jungferstein) and in southern France (contact limestone included in Oben basalts).

In the first article the following points are included:

(*a*) A new deposit of hibschite is mentioned: Albian contact marls, found in the neighborhood of the Village of Nikortzminda, Georgia.

(*b*) A characteristic paragenesis of hibschite similar to that mentioned by Cornu is described, in the present case associated with ferrocalcareous garnet; the octahedral shells of hibschite surrounding the dodecahedral nuclei of the garnet.

(*c*) The present generally accepted formula of hibschite ($CaO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) is criticized and revised on account of the unsatisfactory character of the original material used by Cornu.

In the second article:

(*a*) We described methods used to separate hibschite from the granite of Nikortzminda and which resulted in obtaining two concentrates: (1) hibschite concentrates containing 8% of garnet and 2% of calcite, and (2) garnet, with 7.5% hibschite and 4% calcite content.

(*b*) These concentrates were analyzed by I. M. Shumilo whose results are given in Table 1.

(*c*) Our final conclusions are given as to the chemical composition of hibschite (column 1, Table 1) and of the correct formula of this mineral, which is: $3(Ca,Mg)O \cdot (Al,Fe)_2O_3 \cdot 2(Si,Ti)O_2 \cdot 2H_2O$, or in a simplified form: $3CaO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$.

The chemical composition of the Nikortzminda hibschite (1) and Crestmore plazolite (2) and (3) are recorded in Table 1

As can be seen, the result is rather unexpected: hibschite appears to be more highly calcareous than it was considered heretofore. The ratio $CaO:Al_2O_3$ in its present formula is not as in anorthite, as stated by Cornu, but rather as in grossularite. Thus, it is simply grossularite, in which one molecule of SiO_2 is replaced by two molecules of H_2O.

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[1] Belyankin D. S. and Petrov, V. P., Hibschite in Georgia: *Doklady of the Academy of Sciences, U.S.S.R.*, **24,** No. 4, 1939.

[2] Belyankin, D. S. and Petrov., V. P., Reexamining the chemical formula of hibschite: *Doklady of the Academy of Sciences, U.S.S.R.*, **30,** No. 5, 1941.

These results draw our attention to another similar case of substitution in grossularite found in the literature, namely, that of plazolite from Crestmore, near Riverside, California, which was described by Foshag (1920, 1924). The chemical formula of this mineral: $3CaO \cdot Al_2O_3 \cdot 2(SiO_2 \cdot CO_2) \cdot 2H_2O$ was obtained by this investigator as a result of two chemical analyses given in columns 2 and 3 of Table 1. In Table 2 we compare the occurrence, paragenesis, and properties of the Bohemian and Caucasian hibschites with those of the Californian plazolite described by Foshag.

TABLE 1.

	1		2		3	
	weight %	mol. quant.	weight %	mol. quant.	weight %	mol. quant.
SiO_2	27.57	0.4590	23.85	0.397	25.06	0.417
TiO_2	0.67	0.0084	—	—	—	—
Al_2O_3	18.52	0.1817	22.77	0.223	24.63	0.241
Fe_2O_3	3.70	0.0232	—	—	—	—
FeO	0.15	0.0020	—	—	—	—
MnO	0.08	0.0011	—	—	—	—
CaO	38.39	0.6885	40.13	0.716	40.13	0.716
MgO	2.13	0.0528	—	—	trace	—
H_2O-	0.29	0.0133	9.39	0.521	9.04	0.502
H_2O+	8.55	0.4740				
CO_2	—	—	3.41	0.077	1.13	0.025
Total	100.00		99.55		99.99	

As may be seen from the tables, hibschite and plazolite are very much alike in their properties. Chemically, plazolite differs only by a small and rather variable content of CO_2,[3] and geometrically by the form of its crystals which are dodecahedral instead of octahedral, as in the case of hibschite. Thus, evidently hibschite and plazolite are both members of the same mineral group, for which a preliminary name of *grossularoid group* is being suggested, because of its close relationship to grossularite.

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[3] The role of CO_2 in plazolite is not quite clear. Judging from the fact that its content is highly variable in different analyses, falling sometimes as low as 1%, one may suppose that, similar to the case of Nikortzminda hibschite, it may be present in the form of the secondary carbonate of calcium which partly replaces grossularoid. It also seems quite strange to us that in spite of the fact that plazolite is of a somewhat yellowish color, iron oxides are absent in the analysis of this mineral. Additional study of plazolite from the point of view of these two properties would be highly desirable.

Both hibschite and plazolite are at present considered as very rare minerals. However, we are of the opinion that this conception is not correct. We simply do not distinguish these grossularoids from garnet in some of their occurrences, namely, in contact marls with the characteristic paragenesis: zeolites, calcareous hydrosilicates, garnet, gehlenite, etc.

Table 2. Occurrence and Properties of Hibschite and Plazolite

Mineral	Hibschite		Plazolite
Deposit	Marienberg, Bohemia	Nikortzminda, Caucasus	Riverside, California
Occurrence	In contact metamorphosed marls adjoining phonolite	In contact metamorphosed marls adjoining teschenite	In contact metamorphosed marls adjoining granodiorite
Paragenesis	Apophyllite, Natrolite, Garnet	Apophyllite, Thomsonite, Xonotlite, Wollastonite, Garnet, Hedenbergite	Jurupaite, Riversidite, Wollastonite, Diopside, Vesuvianite, Garnet
Habit of crystals	Octahedral	Octahedral	Dodecahedral
Structure	Structure similar to grossularite as shown by the zonal overgrowth on crystals of the latter mineral		Almost the same structure as grossularite according to x-ray data (Pabst, 1937)
Specific gravity	3.05	3.06 ± 0.03	3.129
Hardness	6.0	—	6.5
Light refraction	$N = 1.67$	$N_{Na} = 1.681$ $N_{500} = 1.695 \pm 0.001$ $N_{580} = 1.682 \pm 0.001$ $N_{615} = 1.671 \pm 0.001$	$N = 1.675$
Solubility	Soluble in acids		Easily soluble in acids
Chemical formula	$3CaO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$		$3CaO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$

In this connection it is interesting to mention that an examination of a suite of minerals from one of such deposits in Transcaucasia, where xonotlite and gehlenite had previously beeen reported (Barsanov, 1937), proved that they contained grossularoid as well. This deposit is situated in the Lopan gorge of southern Osetia and represents a narrow band in the lower Cambrian limestone adjoining a diabasic dyke of Jurassic age.

Here, the same as was the case in Nikortzminda, grossularoid forms shells around the diamond-shaped dodecahedral nuclei of garnet. If these nuclei are very small the shape of their grossularoid shells appears octahedral, like those of typical hibschite; if, on the contrary, the nuclei are larger, and the shell thin, it appears dodecahedral, as that described by Cornu (see his drawing No. 2, 1907, p. 463).

The refractive indices of the Lopan minerals as determined by the immersion method in Na-light are: grossularoid, $N=1.686$, garnet, $N=1.822$.

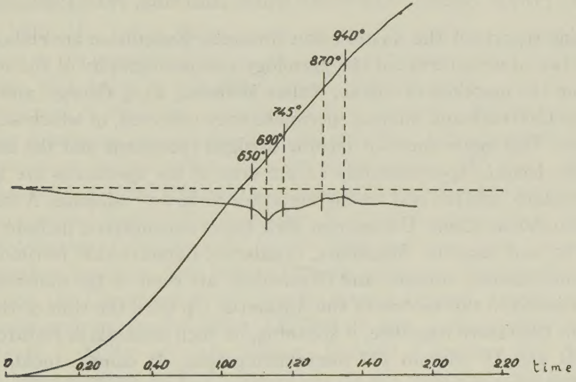

FIG. 1. Heating curve obtained on hibschite concentrate.

Returning to the hibschite of Nikortzminda, we should like to add to the above data the following heating curve, obtained by G. V. Shamkova (Fig. 1). The hibschite concentrate analyzed by I. M. Shumilo served as material for her investigation. Although its quantity was very small (0.5 gr.), the heating curve shows quite distinctly three characteristic thermal effects, one of which is endothermal at a temperature of 650°–690° C, and the remaining two exothermal at 870° C and 940° C. It is possible that the endothermal effect shows, as is the case of kaolin, the transition from the original crystalline substance into an amorphous phase while the exothermal ones show the transition from the amorphous into a crystalline phase and the recrystallization of the resultant crystals into new mineralogical forms.

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FOSHAG, W. F., *Am. Mineral.*, **5**, No. 11, 183–185 (1920); **9**, No. 4, 94 (1924).

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BOOK REVIEWS

AUSTRALASIAN ANTARCTIC EXPEDITION, 1911–1914, under the leadership of Sir Douglas Mawson. *Scientific Reports* by W. R. Browne, A. L. Coulson, J. O. G. Glastonbury, F. L. Stillwell, and C. E. Tilley. Series A, Vol. **III**, Parts I–VI, 330 pp., 45 pls., 14 figs. Government Printer, *Sydney*, New South Wales, Australia, 1918–1940. Price £2 12s 6d.

AUSTRALASIAN ANTARCTIC EXPEDITION, 1911–1914, under the leadership of Sir Douglas Mawson, *Scientific Reports* by P. G. W. Bayly, A. B. Edwards, J. O. G. Glastonbury, A. W. Kleeman, Douglas Mawson, S. R. Nockolds, F. L. Stillwell, H. S. Summers, and C. E. Tilley. Series A, Vol. **IV**, Parts I–XIII, 429 pp., 18 pls., 34 figs. Government Printer, *Sydney*, New South Wales, Australia, 1923–1940. Price £2 12s 9d.

The scientific reports of the Australasian Antarctic Expedition are embodied in a ten volume series, two of which treat of the petrology and petrography of the rocks collected *in situ* and from the moraines of Adelie, Kaiser Wilhelm, King George, and Queen Mary Lands. Close to 1500 rock and mineral specimens were collected, of which well over 50 per cent are erratics. This figure does not include dredged specimens and the large collection from Macquarie Island. Approximately 15 per cent of the specimens are igneous, three per cent sedimentary, and the rest are metamorphic rocks and minerals. A stony meteorite is reported from Adelie Land. Uncommon rock types encountered include charnockites, pseudotachylyte, and jaspilite. Atacamite, cassiterite, dumortierite, ferrimolybdite, gold, kornuperine, molybdenite, stibnite, and tetrahedrite are some of the minerals reported by Mawson as occurring in this section of the Antarctic. Up until the time of the publication of the reports in 1940 there was little, if anything, on such minerals in Antarctic literature.

Volumes III and IV contain 137 photomicrographs, 31 camera lucida drawings, 93 photographs of specimens, outcrop areas, etc., 26 chemical analyses of rocks, eight chemical analyses of minerals, one chemical analysis of rookery liquors, one chemical analysis of "soil," analyses of the meteorite, six approximate chemical analyses derived from Rosiwal analyses, 125 quantitative microscopical analyses and a number of approximate percentage compositions of rock constituents. The chemical analyses are quite complete, including, aside from the "standard" oxides, in many instances, Cr_2O_3, NiO, CoO, and BaO.

There are few typographical errors. On page 394, Volume IV, Part 12, "West Antartica" should read "East Antarctica." Such terminology as that used by Kleeman in referring to twin lamellae that "peter out" is rather descriptive.

Little attempt is made to compare the rocks collected with those of other Antarctic lands, with the exception of Nockolds' contribution.

The microscopical descriptions of the individual minerals of the various rocks are quite detailed, but much less space would be required if the qualitative microscopical analyses were tabulated.

The whole work is exceptionally well done, and is a most excellent addition to the publications on Antarctic petrology and petrography.

Duncan Stewart, Jr.

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB

The American Museum of Natural History, New York City
May, 1940 to April, 1941 Minutes

The New York Mineralogical Club enjoyed a very successful year, attendance at the meetings averaging 67. Two excursions were sponsored, the spring trip to the Sparta and McAfee quarries in New Jersey, and the fall trip to Mt. Adam and Pine Island in New York. A number of good specimens were collected, the most interesting being the small pink spinel crystals at Sparta and the fine scapolite crystals at Pine Island.

The programs have been varied, both scientific and popular. All have been well received and the members have gained in new knowledge and their mineralogical interests have been stimulated.

In May, 1940, Mr. Louis Moyd spoke on the *Mineralogy of Metamorphosed Limestones*, referring to the quarries visited on the spring excursion and other localities, particularly in Canada, with which he is familiar. At the first fall meeting, the Club adhered to its traditional program of members' accounts of their *Summer Collecting Experiences* and a number of fine specimens were shown. Prof. Paul F. Kerr told about some of the *Western Tungsten Deposits* at the November meeting. In December, Mr. O. C. Ralston spoke of *Queer and Unusual Industrial Minerals*, and illustrated his talk with such paradoxical specimens as bentonite and flexible sandstone. Mr. R. C. Wells spoke at the January meeting about the *Distribution of Nickel in the Earth's Crust* and gave some interesting statistics based upon modern analyses. This talk was closely related to the February lecture by Dr. E. G. Zies upon the *Concentration of Elements through Igneous Activity*, which was illustrated with some very spectacular slides. This talk, in turn, lead up to that of the succeeding month by Dr. B. L. Miller upon the *Volcanic Deposits of Sulphur*. The Annual Meeting, held in April, was addressed by R. Emmett Doherty who told about the *Delaware Aqueduct* and some of the experiences and minerals encountered in shafts 7 and 8.

At the April meeting, the following officers were elected to serve for the coming year, to take office at the close of the May meeting:

President:	John N. Trainer
1st Vice-President:	Walter E. Kuenstler
2d Vice-President:	Frederick H. Pough
Secretary:	M. Allen Northup
Treasurer:	James A. Taylor

Directors
Harry R. Lee
Gilman S. Stanton

During the year the Club mineral collection was gone over and much worthless material discarded. Under the Chairmanship of Mr. Frank A. Lewis, good work was done by the Curators' Committee and the collection considerably improved. The Club looks forward to another successful year in 1941–1942 under the new officers.

F. H. Pough, *Secretary*

NEW MINERAL NAMES

Stibarsen

P. E. Wretblad: Minerals of the Varuträsk pegmatite, XX. Die allemontite und das system As-Sb. *Geol. För. Förh.*, **63**, 19–48 (1941).

X-ray, optical, and chemical study of allemontites shows that there are three types

I. Heterogeneous aggregate of phase *A* and phase *B*.
II. Homogeneous, Phase *B*.
III. Heterogeneous aggregate of phase *B* and phase *C*.

It is shown that phase *A* is Sb, containing no As, or so little that *x*-ray study shows very little difference in the cell constants. Phase *C* is As, containing very little or no Sb. Phase *B* is a compound of composition AsSb, as shown by the compositions of Type II, and by analyzing the residue left after dissolving out phases *A* or *C*. The name stibarsen is proposed for this mineral, the name allemontite to be used for the mixtures of stibarsen with either arsenic or antimony. Stibarsen is rhombohedral with cell constants intermediate between those of arsenic and antimony. Determinations by various observers, quoted from the literature, are

r 4.300	α 56.14°
4.27	55.60
4.298	55.26
4.275	55.85
4.279	55.88

It is not clear whether the variation is due to experimental error, or to solid solution.

Michael Fleischer

The Third Roebling Medal

It is believed that members of the society will be interested to learn that the third Roebling Medal was forwarded to England by plane through the courtesy of the British Foreign Office, and was exhibited by Dr. L. J. Spencer at a tea on Thursday, June 5th, 1941, in the apartments of the Geological Society of London.

Respectfully submitted,
Paul F. Kerr, *Secretary*